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# THE DESIGN AND OPERATION OF A COMPACT, ULTRA FAST CLOSING VALVE FOR DEBRIS MITIGATION

D.K. Abe, J. Golden, and T.G. Johnson  
Berkeley Research Associates  
P.O. Box 852  
Springfield, VA 22150

R. Schneider  
Code R45, Naval Surface Warfare Center  
Dahlgren Division, White Oak Detachment  
10901 New Hampshire Ave.  
Silver Spring, MD 20903-5000

## Abstract

Presently, radiation simulators utilizing plasma radiation sources (PRS) generate large amounts of undesirable debris which can potentially damage the objects under test. The Ultra Fast Closing Valve (UFCV) is a fast acting foil shutter (cross-sectional area = 1 cm × 4 cm) which erects a physical barrier to the slower moving debris after allowing the passage of x-ray photons. The UFCV consists of a metallic foil cassette which is imploded by an outer magnetic field generated by a fast capacitor discharge into a single turn loop. Typical capacitor bank charging voltages range from 15 to 25 kV, with corresponding currents of approximately 80 to 130 kA. Valve closure times as fast as 27 microseconds have been observed. The design and construction of the unit are presented along with the results of measurements of valve closure velocities.

## Introduction

A number of presently operating and proposed radiation simulators utilize a Plasma Radiation Source (PRS) to produce x-ray spectra of interest. Such sources generate a hot, dense plasma which is formed when a large amount of current (typically in the range of 100 kA – 10 MA) is rapidly discharged into a small amount of plasma forming material suspended between a pair of electrodes. Typical examples of PRS x-ray sources include wire arrays and z-pinches.

An example is a z-pinch PRS in which the current is rapidly discharged into a plasma forming load which may be a pre-ionized gas, a neutral gas, or an array of thin wires arranged in parallel. The rapid discharge of current ohmically heats and ionizes the load; a plasma is created. The plasma pinches and is accelerated toward the axis of symmetry by the  $\vec{J} \times \vec{B}$  force created by its own current and self-magnetic field [1]. Dense plasmas produced in this fashion are efficient x-ray sources [2].

As a consequence of the violent plasma formation processes, a number of undesirable byproducts are formed in addition to the desired x-ray radiation. These byproducts can include material debris ejected from the diode structure and solid and molten pieces of the load which have escaped ionization, explosively expanding hot gases, charged particles, and sub-keV photons. All of these byproducts may cause detrimental effects on both the object under test and the test diagnostics.

Thin foils which are mostly transparent to x-rays but dense enough to stop gaseous and/or macroscopic ejecta have been used in the past for debris mitigation. However, at high energy fluxes, these foils are subject to ablation and may become sources of debris themselves. Furthermore, they may unacceptably attenuate the desired photon flux.

A magnetically imploded foil valve is a robust alternative to the thin foil window. Shown in schematic in Fig. 1, the active part of the valve consists of an insulated, low mass, metallic foil loop that is mounted in a massive, slotted metal block. The loop and the slotted block form a 1:1 transformer. During valve operation, current is rapidly discharged through the primary which is defined by the slot and a milled aperture in the block; the resulting azimuthally flowing current generates an outer magnetic field which exerts an inward radial pressure on the diamagnetic foil loop secondary. The magnetic pressure crushes the foil.

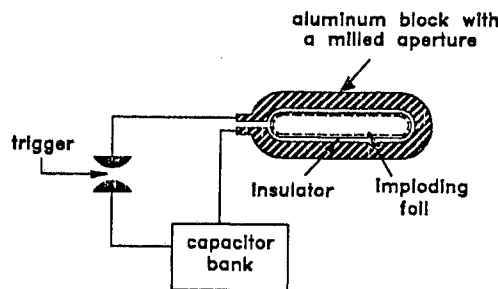


Figure 1: Magnetically imploded foil valve schematic

## Ultra Fast Closing Valve (UFCV)

Magnetically imploded foil valves are not intrinsically new devices, cf. Ref. [3] and the work done by Maxwell Laboratories (ca. 1988). The technical challenges for the device include minimizing the pulsed power requirements and optimizing the design of the foil cassette in order to mitigate plasma production at the foil edge (arcing) and to maximize the valve closure velocity.

Berkeley Research Associates (BRA) has designed and constructed a compact ( $\sim 1.3$  m<sup>3</sup> total volume), 10  $\mu$ F, 40 kV capacitor bank to drive an Ultra Fast Closing Valve (UFCV). The UFCV is presently deployed at a PRS simulator at the Naval Surface Warfare Center, White Oak Detachment, for use with a cryogenic debris shield. The UFCV consists of a 1 cm × 4 cm milled aluminum aperture with a novel multi-layer thin aluminum foil acting as the valve. The foil is packaged in a Kapton dielectric shell, which insulates the foil from the aperture and forms the body of the valve cassette. Some edge treatment of the foil was necessary to prevent the formation of plasma. An electrical schematic of the UFCV is shown in Fig. 2.

Typical bank charging voltages ranged from 15 to 25 kV, with corresponding currents of approximately 80 to 130 kA. Fig. 3 is a typical UFCV current waveform (17 kV charge); the quarter cycle time in this case is  $\sim 3$   $\mu$ s.

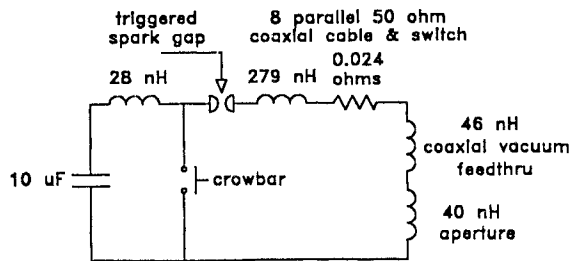


Figure 2: UFCV electrical schematic

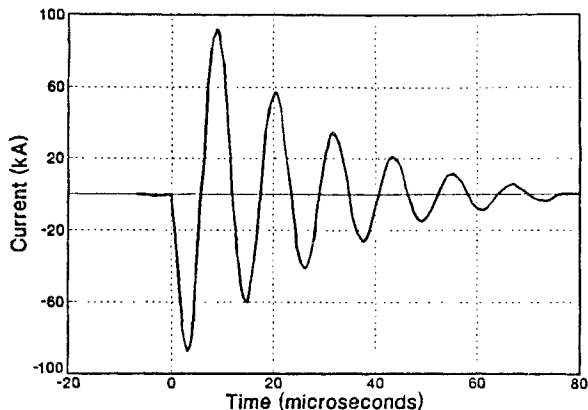


Figure 3: Typical UFCV current waveform (V=17 kV)

utilized a 2 mW HeNe laser light source focused through a short focal length lens ( $< 5$  cm) to quasi-uniformly illuminate the UFCV opening. The UFCV was placed  $\sim 0.5$  m from the short focal length lens. A 1 m focal length lens was placed immediately downstream of the UFCV. This lens transferred the beam onto a turning mirror. From the mirror, a +15 cm focal length lens was used to focus the beam onto the polished end of a fiberoptic cable. An Optometrics monochromator was placed between this last lens and the fiberoptic in order to eliminate all light sources other than the laser ( $\lambda = 632.8$  nm) from impinging on the photodiode.

The valve closure time measurements were performed in air; slightly higher closure velocities for the same bank parameters are expected in vacuum. The fastest closure time of  $\sim 27 \mu\text{s}$  was obtained for a bank charge voltage of 22 kV with a valve constructed from 3.5 layers of  $\sim 0.038$  mm (1.5 mil) thick aluminum foil. The foil edges were treated to prevent arcing. Higher bank charge voltages (i.e., higher discharge currents) tended to tear the foil. More massive foils resisted tearing but did not show any improvement in closure time. Fig. 5 shows the bank current and photodiode waveforms for the optimized 22 kV shot.

An approximate relation for the closure time can be obtained from Newton's law, assuming that the magnetic pressure remains constant throughout the pulse. This relation yields a closure time that is inversely proportional to the primary driver current and proportional to the square root of the mass of the foil. The experimentally measured closure times are consistent with the predictions made by the simple model.

#### UFCV Closure Time Measurements

The valve closure time is a key figure of merit for the UFCV; an experimental technique was developed which allowed for the precise measurement of this closing time. A schematic of the experiment is shown in Fig. 4. The measurement technique

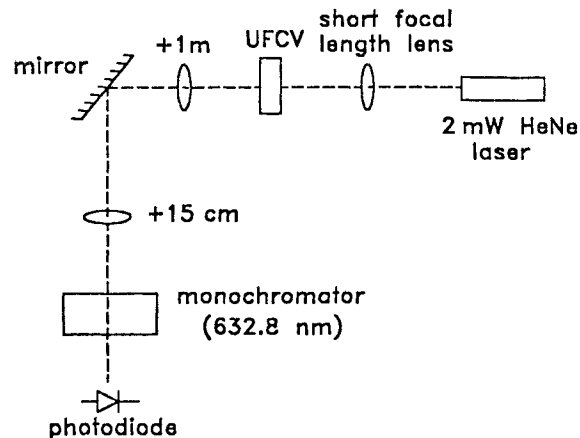


Figure 4: UFCV closure time measurement experiment schematic

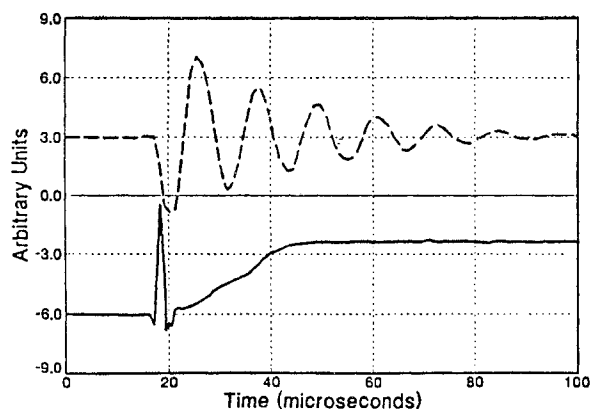


Figure 5: Bank current (top) and photodiode (bottom) waveform for optimized 22 kV UFCV shot

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